ENGINEERING PROPERTIES OF WARM MIX ASPHALT USING EMULSION AS AN ADDITIVE

A project submitted in partial fulfillment of the requirements for the degree of

Bachelor of technology

In

Civil Engineering

By

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ROURKELA

Certificate

This is to certify that the thesis entitled "**ENGINEERING PROPERTIES OF WARM MIX ASPHALT USING EMULSION AS AN ADDITIVE**" submitted by PRASANTA KUMAR PATRA in partial fulfillment for the requirement for the award of Bachelor in Technology degree in Civil Engineering at National Institute of Technology, Rourkela, is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the contents in this thesis have not been submitted to any other University/Institute for the award of any degree or Diploma.

Prof. Mahabir Panda

Department of Civil Engineering

National Institute of Technology

Rourkela-769008

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ABSTRACT

Warm Mix Asphalt (WMA) technology is recently developed in Europe and is gaining strong interest worldwide. By lowering the viscosity of bitumen binder, WMA technology allows mixing, transporting and gives better workability at lower temperature. Using WMA technology, asphalt mix can be produced which is 30°C to 40°C lower than hot mix asphalt (HMA). Less emission, savings in energy cost, less odor are there because of lower mixing and compaction temperature. Despite the benefits, researches are there to analyze its long-term performance.

This project was carried out to evaluate the suitability of bitumen emulsion as an additive when applied to WMA samples of Stone Matrix Asphalt (SMA) and Dense Bituminous Macadam (DBM) mix as per MORTH specification. The binder content has been varied from 4 % to 7 % by weight of aggregates for both mixes. Cement and stone dust have been used as filler for DBM and SMA mixes respectively. VG 30 grade bitumen has been used as binder for both mixes. The optimum binder content for SMA and DBM mixes were found to be 5.93% and 5.33%.

Key Words: Stone Matrix Asphalt (SMA), Dense Bituminous Macadam (DBM), Emulsion (CMS), Marshall Properties

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Nomenclature

G_{sb} – Bulk specific gravity of aggregates

G_{se} – Effective specific gravity of aggregates in mix

G_a – Apparent specific gravity of aggregates

G_{mm} – Theoretical maximum specific gravity of the mix

G_{mb} – Bulk Specific gravity of the mix

VMA – Voids in mineral aggregates

VA – Air void

VFB – Voids filled with bitumen

B_{vs} – Bulk volume of sample

HMA- Hot Mix Asphalt

WMA-Warm Mix Asphalt

DBM-Dense Bituminous Macadam

SMA-Stone Matrix Asphalt

Chapter I

INTRODUCTION

1.1 Introduction

Warm Mix Asphalt (WMA) is a fast emerging new technology with potential of revolutionizing the production of asphalt mixtures. WMA technology allows the mixing, and compaction of asphalt at 30°C to 40°C lower temperatures compared to Hot Mix Asphalt (HMA). The technology can reduce production temperatures by as much as 30 percent. Hot asphalt mixes are generally produced at 150º C where WMA mixes are produced at temperatures of about 120ºC or lower.

1.2 Warm Mix Asphalt Technologies

1.2.1 By use of water

In this technology when small amount of water turns into steam at atmospheric pressure, it expands in volume by a factor of 1.673. This causes increase in the volume of asphalt binder, which helps in coating the aggregate and lowers the mix apparent viscosity.

1.2.2 By use of organic additives

In this technology, organic additives or waxes are used which lower the asphalt binder viscosity above their melting points.

1.2.3 By use of chemical additives

In this technology, some chemical additives are used to produce a variety of different mechanisms to coat the aggregate at lower temperatures.

1.3 Benefits of WMA over HMA

These are the benefits of WMA over HMA:

- Mixed at low temperatures
- Consumption of energy is less

- WMA produces less emissions from the burning of fossil fuels than HMA
- Decreased binder aging because the loss of lighter oils is less as compared to HMA at lower mixing temperatures
- RAP (reclaimed asphalt pavement) will be increased in WMA compared to HMA during hot recycling
- Production of dust is less due to lower temperatures and shorter heating time
- The main economic benefit of WMA comes from the energy savings. There is a reduction of 20 to 75 percent energy in wma as compared to HMA

1.4 Objectives

- To prepare warm mix asphalt (WMA) samples adding emulsion as an additive.
- To determine the stability of WMA samples by Marshall Stability test.
- To evaluate the engineering properties and performances of WMA samples.

Chapter II

REVIEW OF LITERATURE

2.1 Background

Now a days Warm Mix Asphalt (WMA) is widely used all over the world because of its numbers of advantages as compared to Hot Mix Asphalt (HMA). In recent past many researchers were analyzed and developed various conventional methods for WMA. Some of these technics are

Meadwestvaco (2003) performed laboratory study to determine applicability of Evotherm for typical paving operation using aggregate size PG 64-22. He found that addition of Evotherm as an additive reduce air pollution at 46% reduction in Co_2 , 81% in Sox and 63% in Co.

Oke Oluwaseyi 'Lanre (2010) examined the performance of bitumen emulsion stabilized RAP (reclaimed asphalt pavement) with the hope of establishing a practical procedure for the use of RAP in road base construction in Nigeria.

Zun jhang (2010) studied the effects of warm mix asphalts additives on asphalt mixture characteristics and pavement performance. The primary objective of this research is to evaluate the feasibility of several WMA mixtures as potential asphalt paving mixtures and also, three well-known WMA additives (i.e. Sasobit, Evotherm, and Advera synthetic zeolite) were evaluated.

European Asphalt Pavement Association (2010) focuses on Warm Mix Asphalt (WMA) technologies for producing asphalt at temperatures slightly above 100 °C with properties or performance equivalent to that of conventional HMA.

Maria del Mar Colas Victoria (2010) researched to develop cold mix and warm mix emulsion with ecological fluxes and found it as an environmentally friendly solution with no curing period needed.

Yong-Rak Kim, Jun Zhang , Hoki Ban (2011) evaluated the moisture damage in WMA with the inclusion of fractionated RAP produced by Tennessee contractors. In addition to traditional AASHTO T283 freeze and thaw tensile strength ratio, three other moisture damage tests were evaluated to determine the practicality of their use: Hamburg, dynamic modulus ratio, and tensile strength ratio with MIST conditioning.

Marisa Dinis-Almeida and joao Castro -Gomes (2011) studied about defining and developing design mix method of Recycled Asphalt Pavement. They were compacted the RAP with emulsion content of 1.5%. 2%, 2.5% and 3 % at two different temperature (60^0C and 90^0C).The observation concluded the best results for mixtures compacted at 90°C.

Yu Kuang (2012) evaluated the performance of Evotherm 3G as WMA technology and as an anti-strip additive. There are two main objectives through this research. Yu kuang's first objective is to evaluate performance of the Evotherm–J1 and the Evotherm–M1 as a compaction technology additive. His second objective is to study the effect of moisture anti-strip of the Evotherm–J1 and the Evotherm–M1.

Lu and Redelius (2012) studied the effect of asphalt that contains wax naturally. They concluded that using waxy bitumen, the asphalt mixtures showed higher fracture temperature. They found that adding wax to asphalt does not affect the water sensitivity in any way

2.2 Summary

There are a number of different processes that can create WMA. All processes involve combining some type of additives to the binder, whether it is water or a chemical or organic compound. The addition of Evotherm as an additive reduce air pollution .Various Binder properties affect the performance of the warm mix technologies differently .The aggregates also affects the moisture susceptibility, rutting potential and resilient modulus,

Chapter III

EXPERIMENTAL

OVERVIEW

3.1 Materials Used

3.1.1 Coarse and Fine Aggregate

According to BIS 383:1963 aggregates which are retained on 4.75 mm BIS Sieve is defined as coarse aggregate and which will pass through 4.75 mm BIS Sieve is defined as fine aggregate. The Ministry of Road Transport and Highways (MORTH) recommended gradation as per nominal maximum size of aggregate (NMSA) 19 mm for DBM and 13mm for SMA shown in Table 3.1 and Table 3.2. The laboratory test results of aggregates have been given in Table 3.3.

Table 3.1: Gradation for DBM (MORTH)

BIS Sieve	**% passing (range)**	**%passing (adopted)**
26.5	100	100
19	90-100	95
13.2	56-88	72
4.75	16-36	26
2.36	4-19	11.5
0.3	2-10	6
0.075	0-8	4
Bitumen content (%)	4-7	4-7

Table 3.2: Gradation for SMA (MORTH)

BIS Sieve	% passing (range)	%passing (adopted)
26.5	-	-
19	100	100
13.2	90-100	95
9.5	50-75	62.5
4.75	20-28	24
2.36	16-24	20
1.18	13-21	17
0.6	12-18	15
0.3	10-20	15
0.075	8-12	10
Binder Content (%)	5-7	5-7

Table 3.3: Laboratory test result of aggregate

Test of Aggregates	Laboratory Results
Impact Value (BIS 2386-Part IV)	14.73 %
crushing value(BIS 2386-Part IV)	14.69%
Los Angel's Abrasion Value (BIS 2386-Part IV)	15.86%
Specific Gravity (BIS 2386- Part III)	2.8
Flakiness (BIS 2386-part IV)	18.88%
Elongation Index (IS 2386-part IV)	21.64%

3.1.2 Binder

Bitumen is a non-crystalline viscous material black/ dark brown in colour, which is substantially soluble in carbon disulphide (CS_2), having adhesive and water-proofing qualities. It consists of hydrocarbons having 80% carbon and 15% hydrogen, the rest 5 % is oxygen, sulphur and nitrogen. Bitumen acts as a binder in SMA and DBM mix. In the study preparation of SMA and DBM mix VG 30 bitumen used as binder. Penetration Test determines the hardness of Bitumen by measuring the depth.

3.1.3 Emulsion (CMS)

In the experiment Cationic medium setting (CMS) emulsion is used. Cationic defines that the particles of the emulsions are contains positive charge. Here the break is sufficiently slow so that the emulsion can be mixed with aggregate containing a high proportion of fine materials.

3.1.4 Filler

Filler fills the voids between aggregate grains and improves the wearing capabilities of mix. It is stored and fed dry into the mix, during or after addition of binder. Stone dust, slag dust, hydrated lime, fly ash, mineral filler and cement are used as filler. Also fine aggregate below 75micron can be used as filler. For this observation stone dust and cement have been used as filler for SMA and DBM composition respectively. The filler also improve the binding property between the aggregate.

3.2 Preparation of Sample

3.2.1 Sieve analysis

Sieve analysis was done by BIS sieve size of 19mm, 13.2mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.075mm and aggregates were collected and stored. Total weight of one sample is 1200 gms. The distribution of aggregates was taken as per Table 3.2 for SMA

composition and Table 3.1 for DBM composition. The samples have been prepared by following steps.

3.2.2 Sampling for Mix

Sampling of coarse and fine aggregates is carried out by 13mm Stone Matrix Asphalt (SMA) composition and 3 samples based on 5%, 5.5%, 6%, 6.5% and 7% bitumen each were prepared. Similarly sampling of coarse and fine aggregates is carried out by 19mm DBM composition and 3 samples based on4%, 5%, 6% and 7% bitumen each were prepared. Then emulsion was added to the samples according to the bitumen content and left for 24 hours. After sampling of aggregates was completed, the dry samples were kept in oven for 2 hours at 110^0C.

3.2.3 Heating of bitumen

VG 30 bitumen was heated with a high temperature for uniform and easy mixing with all aggregates.

Figure 3.1: Heating of bitumen

3.2.4 Mixing of components

Aggregate, bitumen, emulsion and stone dust (in SMA) were mixed to make a homogeneous SMA Mix and in DBM composition we use cement instead of stone dust as filler. After mixing of dry samples with required quantity of binder and emulsion, the mixture was put in to the Marshall moulds diameter in 100 mm. Mould was heated and coated with oil before use so that mixture may not be cold before hammering.

Figure3.2: Mixing of components

3.2.5 Compaction

After putting in mould, hammering was performed. Hammering was done with a standard hammer. Before putting the sample into mould, oiling was done to the bottom of hammer and also to the inner face of the mould so that the sample will not stick to the mould and hammer. Then a piece of paper of diameter equal to the mould was put over fitting. Then 75 blows to each side of the specimen were given for compaction purpose.

Figure 3.3: Specimen mould holder

Figure 3.4: Hammer used for compaction

3.2.6 Finalizing the sample

The sample was taken out of mould after hammering. To recognize it later, name sticks representing sample's binder content, sample number, and type of additives used are glued to sample for example: S1-5%-EMULSION. Then the sample was left to cool down to room temperature.

Figure 3.5: Extraction of sample from mould

Figure 3.6 Prepared Samples

3.3 Experiments Performed

When the samples were prepared they were supposed to go under Marshall Test which was performed as per ASTM D 6927 – 06. This test gives the flow value and stability number of different samples. But before Marshall Test, the samples had to go through certain procedures.

First dry weight of samples are taken and recorded. Weights of samples in water are also needed. So paraffin was heated up to liquefaction and sample is immersed in paraffin by holding it through a thread. Then the sample was allowed to cool so that sample is coated with paraffin. This was done because sample has voids so water may enter in voids. After paraffin coating the weight of sample is taken. Now weight of sample in water is recorded.

After weighing, the sample is put in water bath before testing up to a maximum of 30 minutes. In water bath temperature of 60°C is maintained throughout. After 30 minutes, the samples are ready for Marshall Test.

Figure 3.7: Water bath

3.3.1 Marshall test

The Marshall test was conducted as per given in ASTM D 6927-06. Marshall Test Apparatus has following parts:

3.3.1.1 Breaking Head

The breaking head consists of upper and lower cylindrical segments of cast iron. The lower segment was mounted on a base having two perpendicular guide rods or post extending upwards. Guide sleeves in the upper segment direct the two segments together on the guide rods.

Figure 3.8: Breaking Head of Marshall Apparatus

3.3.1.2 Load Measuring Device

A 25 kN capacity of proving ring was used for testing the specimens. The proving ring is equipped with a micrometer dial graduated in 0.0025 mm increments. The upper portion of the ring is attached to the testing frame and the lower portion transmits the load to the breaking head.

Figure 3.9: Proving Ring

3.3.1.3 Flow value measurement

A dial gauge is used to measure the flow value. By dial gauge initial and final values is recorded and their difference is taken as flow.

Figure 3.10: Flow Measurement in progress

3.4 Test procedure

Immerse the specimens in a water bath at 60°C for 30. Thoroughly clean and lubricate the guide rods so that the upper test head slides freely over them. Remove the specimen from the water bath and place in the breaking head. The elapsed time between removal of the sample from the water bath and maximum load determination shall not exceed 30 sec. Place the complete breaking head assembly in position on the testing machine. Place the flow meters, and adjust it to zero.

Apply the load to the specimen by a constant rate of movement of the testing machine head of 50 mm per minute until a maximum load is reached and the load decreases as indicated by the proving ring dial. Record the proving ring micrometer dial reading. The total maximum in kN (that causes failure of the specimen) is taken as Marshall Stability. The stability value obtained is corrected for volume by using correlation ratio table. The total amount of deformation in units of 0.25 mm that occurs at maximum load is recorded as Flow Value.

Chapter IV

ANALYSIS OF RESULTS

4.1 Parameters Used

Evaluating specific gravity of an aggregate, some definitions of specific gravity are proposed:

- Bulk specific gravity (G_{mb}) of the mix

  G_{mb} = (M_{mix} /bulk volume of mix)

- Bulk specific gravity (G_{sb}) of aggregates

  G_{sb}= Mass of aggregate / volume of (aggregate mass +air void in aggregate + absorbed bitumen)

- Theoretical maximum specific gravity (G_{mm}) of the mix

  G_{mm} = M_{mix} / volume of (mix−air voids)

- Air voids (VA)

  $VA = (1 - (G_{mb} / G_{mm})) * 100$

- Voids in mineral aggregates (VMA)

  $VMA = (1 - ((G_{mb} / G_{sb}) * P_s)) * 100$

  Where P_s is the % of aggregate present by total mass of the mix.

- Voids filled with bitumen (VFB)

  VFB = ((VMA−VA) / VMA) * 100

- Effective specific gravity (G_{se})

  G_{se} = Mass of aggregate / volume of (aggregate mass + air void in aggregate)

4.2 Test results of SMA

Table 4.1 Physical properties of SMA samples

Sample	Temperature (℃)	Bitumen (%)	Weight of sample in air (gm)	Weight of sample after paraffin coat (gm)	Weight of sample in water (gm)	Height (mm)	Radius (mm)	Weight of aggregate mix (gm)
1	110	5	1197	1211	717	61.5	50	1140
2			1194	1209	713	61.5		1140
3			1199	1213	715	62		1140
1		5.5	1196	1204	706	62		1134
2			1194	1202	703	61.5		1134
3			1197	1206	705	62		1134
1		6	1196	1215	710	62		1128
2			1192	1208	708	61		1128
3			1196	1214	709	61.5		1128
1		6.5	1187	1202	698	60.5		1122
2			1189	1205	705	62		1122
3			1194	1210	713	61		1122
1		7	1196	1217	712	60.5		1116
2			1192	1211	709	61.5		1116
3			1189	1210	708	62		1116

Table 4.2: Weights and Specific Gravities of SMA samples

Binder (%)	**B_{vs}**	**G_{mb}**	**G_{sb}**	**Vol**	**G_{mm}**	**VA (%)**	**Avg. VA**	**VMA (%)**	**Avg VMA**	**VFB (%)**	**Avg VFB (%)**	**G_{se}**
5	495.637	2.404	2.723	479.093	2.556	6.033	6.1	17.224	17.104	63.975	64.5	2.723
	499.556	2.391	2.723	483.020	2.556	6.223		17.101		64.632		2.723
	497.898	2.429	2.723	486.947	2.556	6.044		16.987		64.893		2.723
5.5	488.784	2.414	2.723	494.801	2.556	4.78	4.6	16.001	16.02	69.11	68.5	2.723
	491.576	2.438	2.723	479.093	2.556	4.75		16.114		68.55		2.723
	493.622	2.438	2.723	494.801	2.556	4.27		15.945		67.84		2.723
6	481.200	2.488	2.723	0.000	2.556	3.75	3.8	14.775	15.50	72.22	71.5	2.723
	477.586	2.480	2.723	483.020	2.556	4.10		15.630		71.25		2.723
	484.888	2.433	2.723	479.093	2.556	3.55		16.095		71.03		2.723
6.5	469.789	2.516	2.723	0.000	2.556	2.997	3.3	15.438	15.65	73.5	74	2.723
	471.500	2.437	2.723	479.093	2.556	3.448		15.957		75.25		2.723
	473.886	2.541	2.723	486.947	2.556	3.455		15.555		73.25		2.723
7	468.770	2.452	2.723	0.000	2.556	2.85	3.1	16.443	16.12	76.50	75	2.723
	467.678	2.466	2.723	471.239	2.556	3.25		16.100		74.80		2.723
	469.544	2.502	2.723	479.093	2.556	3.20		15.817		73.70		2.723

Table 4.3 Stability and Flow values of SMA samples

Sample no	Bitumen content (%)	Stability (kN)	Avg. Stability (kN)	Flow (mm)	Avg. flow (mm)
1	5	8.11	8.30	2.6	2.3
2		8.47		2.1	
3		8.32		2.2	
1	5.5	10.88	11.65	2.14	2.38
2		11.94		2.26	
3		12.13		2.74	
1	6	8.84	9.48	2.488	2.533
2		9.28		2.367	
3		10.32		2.744	
1	6.5	8.28	8.10	2.62	2.92
2		8.24		2.98	
3		7.78		3.16	
1	7	7.34	7.50	3.88	4.2
2		7.92		4.26	
3		7.24		4.46	

4.2.1 Relationships on SMA:

4.2.1.1 Binder content vs. stability

Table 4.4 Average stability and Bitumen content for SMA samples

Binder Content (%)	Stability (kN)
5	8.3
5.5	11.65
6	9.48
6.5	8.10
7	7.50

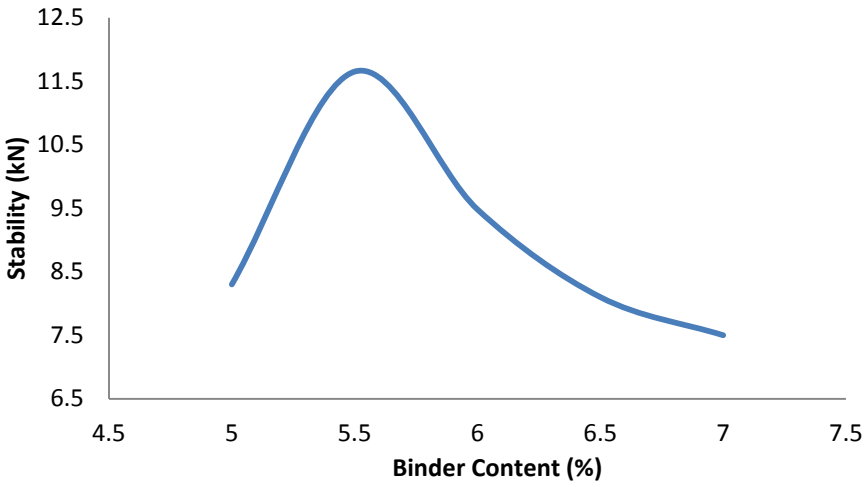

Figure 4.1: Plot between Stability and Binder Content

4.2.1.2 Binder content vs.Flow value

Table 4.5 Average flow value and Bitumen content for SMA samples

Binder content (%)	Flow value(mm)
5	2.3
5.5	2.38
6	2.533
6.5	2.92
7	4.2

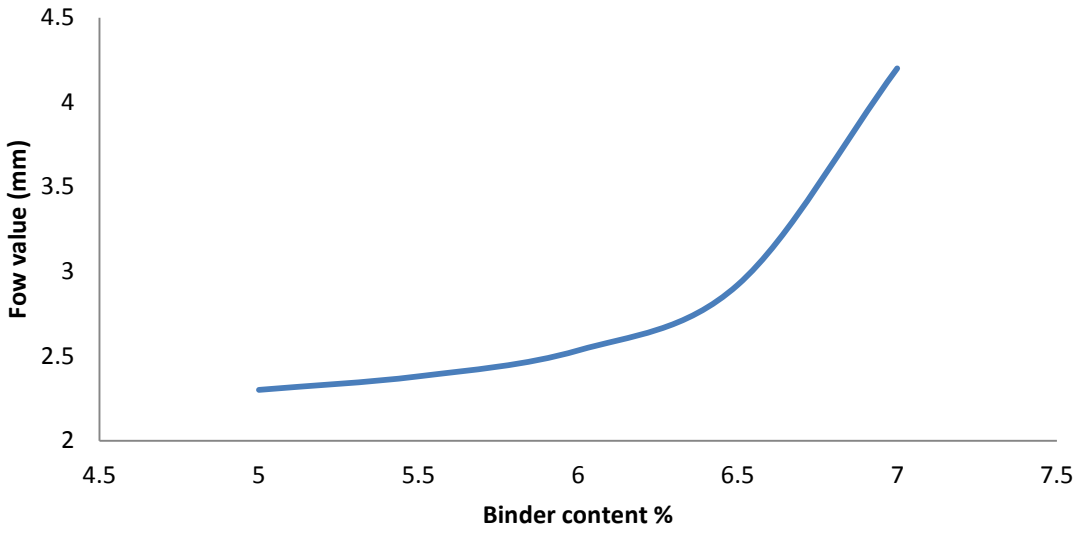

Figure 4.2: Plot between Binder content vs. flow value

4.2.1.3 Binder content vs. VMA

Table 4.6 Average VMA and Bitumen content for SMA samples

Binder content (%)	VMA (%)
5	17.104
5.5	16.02
6	15.5
6.5	15.65
7	16.12

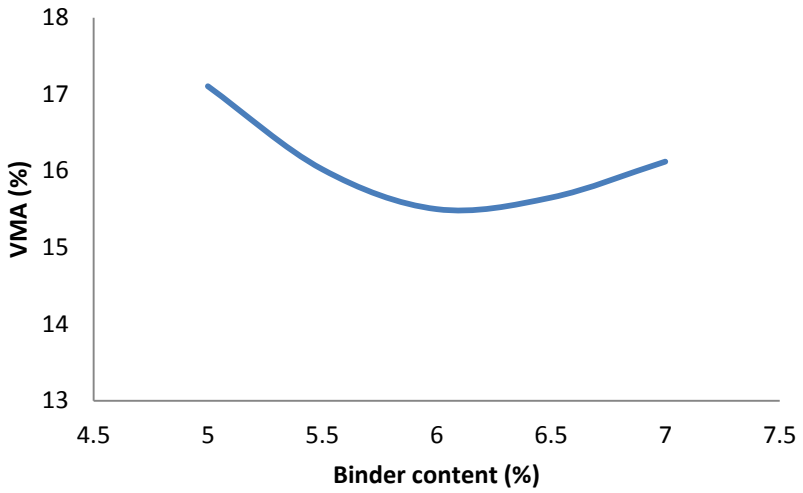

Figure 4.3: Plot between Binder content vs. VMA

4.2.1.4 Binder content vs. VA

Table 4.7 Average VA and Bitumen content for SMA samples

Binder content (%)	VA (%)
5	6.1
5.5	4.6
6	3.8
6.5	3.3
7	3.1

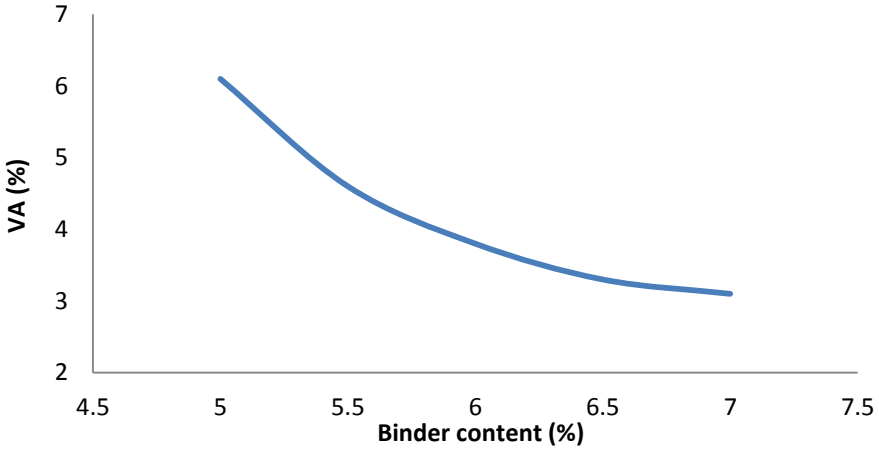

Figure 4.4: Plot between Binder content vs. VA

4.2.1.5 Binder content vs. VFB

Table 4.8 Average VFB and Bitumen content for SMA samples

Binder content (%)	VFB (%)
5	64.5
5.5	68.5
6	71.5
7.5	74
7	75

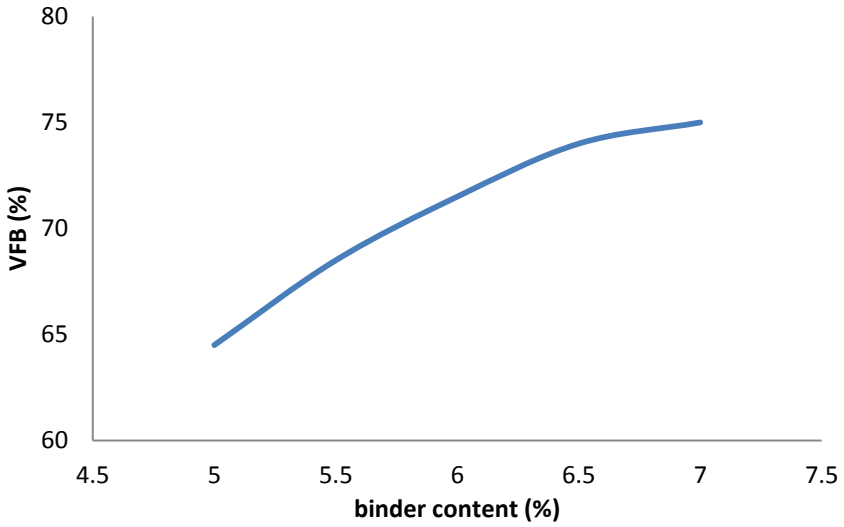

Figure 4.5: Plot between Binder content vs. VFB

4.2.1.6 Binder content vs. Unit weight (G_{mb})

Table 4.9 Average unit weight and bitumen content

Binder content (%)	Unit weight (G_{mb}) (kg/m^3)
5	2.408
5.5	2.43
6	2.467
6.5	2.498
7	2.47

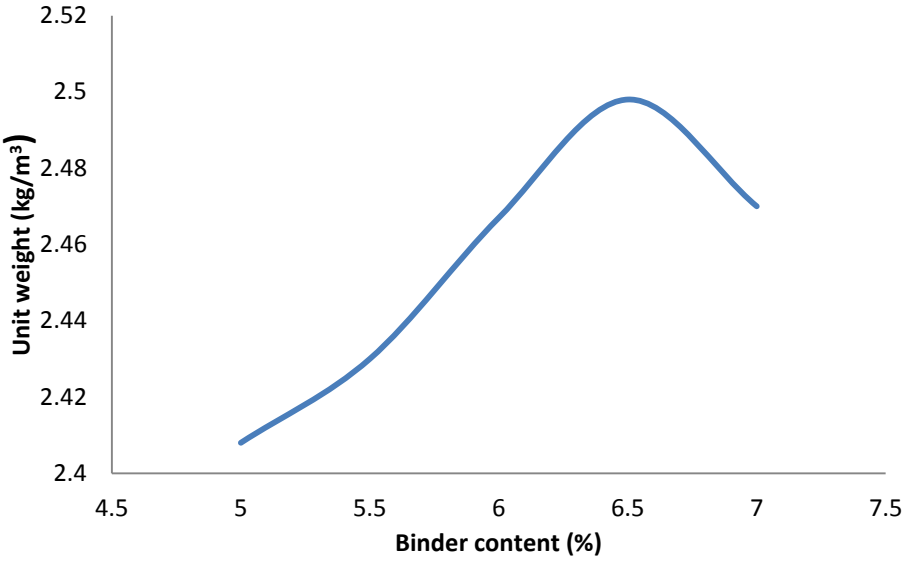

Figure 4.6: Plot between Binder content vs. unit weight

4.3 Test results of DBM:

Table 4.10 Physical properties of DBM samples

Sample	Temperature (℃)	Bitumen (%)	Weight of sample in air Gm)	Weight of sample after paraffin coat(gm)	Weight of sample in water (gm)	Height (mm)	Radius (mm)	Weight of aggregate mix (gm)
1	110	4	1198	1209	706	62	50	1152
2			1195	1204	704	63		1152
3			1195	1205	707	61.5		1152
1		5	1192	1212	703	61.5		1140
2			1194	1213	711	61		1140
3			1195	1217	708	62		1140
1		6	1190	1210	706	62		1128
2			1193	1213	709	61.5		1128
3			1196	1214	709	60		1128
1		7	1199	1204	711	61		1116
2			1199	1205	706	62.5		1116
3			1195	1202	703	61.5		1116

Table 4.11 Weights and Specific Gravities of DBM samples

Binder (%)	Bvs	Gmb	Gsb	Vol	Gmm	VA (%)	Avg. VA (%)	VMA (%)	Avg VMA (%)	VFB (%)	Avg VFB (%)	Gse
4	466.556	2.440	2.723	0.000	2.588	5.751		16.079		64.345		2.723
	472.222	2.431	2.723	479.093	2.588	5.954	5.91	16.029	16.04	64.555	64.5	2.723
	474.333	2.425	2.723	494.801	2.588	6.025		16.012		64.600		2.723
5	480.778	2.473	2.723	0.000	2.588	4.15		13.3		66.50		2.723
	479.778	2.481	2.723	483.020	2.588	4.005	4	14.10	13.6	69.85	68	2.723
	485.000	2.492	2.723	479.093	2.588	3.845		13.4		67.65		2.723
6	468.456	2.539	2.723	0.000	2.588	2.86		13.55		72.05		2.723
	472.564	2.552	2.723	494.801	2.588	2.97	3.1	13.95	14	71.10	71	2.723
	475.433	2.553	2.723	471.239	2.588	3.47		14.5		69.85		2.723
7	481.678	2.506	2.723	0.000	2.588	3.25		13.986		71.50		2.723
	477.678	2.515	2.723	494.801	2.588	2.95	3	14.878	14.44	72.95	72	2.723
	486.987	2.527	2.723	479.093	2.588	2.80		14.456		71.55		2.723

Table 4.12 Stability and Flow values of DBM samples

Sample no	Bitumen content (%)	Stability (kN)	Avg. Stability (kN)	Flow (mm)	Avg. flow(mm)
1	4	8.84	9.22	1.94	2.12
2		9.18		2.1	
3		9.64		2.32	
1	5	12.46	13.28	1.9	2.20
2		14.88		2.1	
3		12.50		2.6	
1	6	10.28	10.65	2.96	2.76
2		10.12		2.5	
3		11.55		2.82	
1	7	8.88	8.64	3.54	3.92
2		8.68		3.88	
3		8.36		4.34	

4.3.1 Relationships of DBM:

4.3.1.1 Binder content vs. stability

Table 4.13 Average stability and Bitumen content for DBM samples

Binder content (%)	Stability (kN)
4	9.22
5	13.28
6	10.65
7	8.64

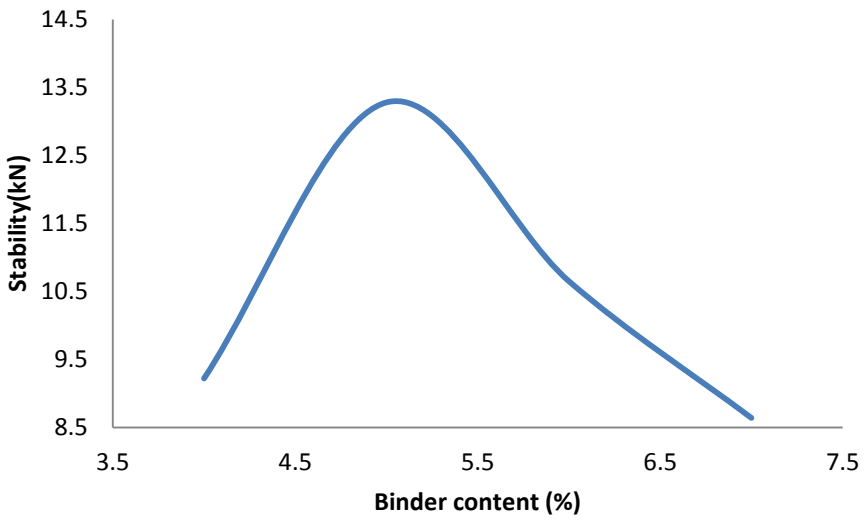

Figure 4.7: Plot between Binder content vs. stability

4.3.1.2 Binder content vs. flow value

Table 4.14 Average flow value and Bitumen content for DBM samples

Binder content (%)	Flow value (mm)
4	2.12
5	2.2
6	2.76
7	3.92

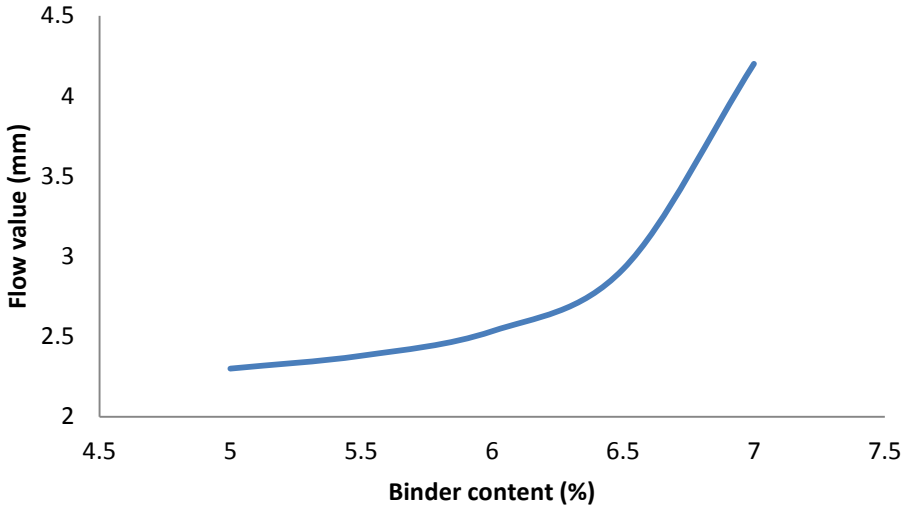

Figure 4.8: Plot between Binder content vs. flow value

4.3.1.3 Binder content vs. VMA

Table 4.15 Average VMA and Bitumen content for DBM samples

Binder content (%)	VMA (%)
4	16.04
5	13.6
6	14
7	14.44

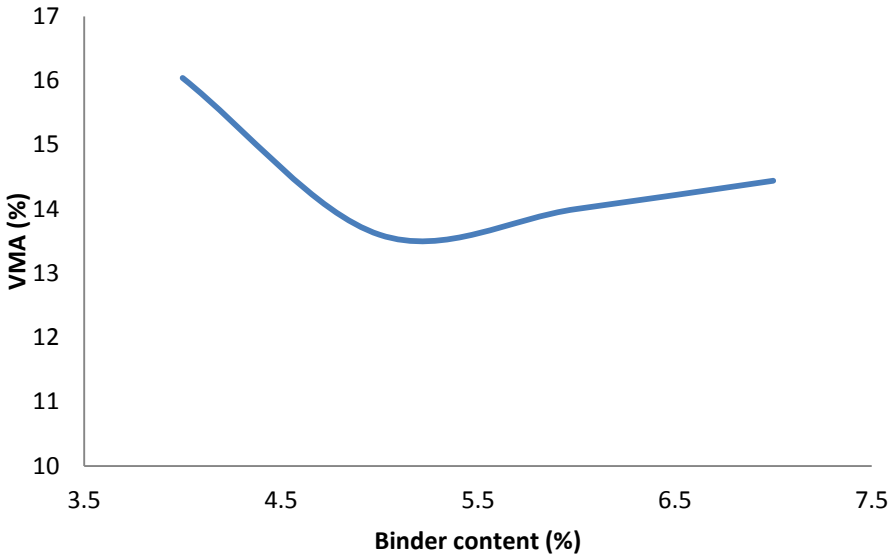

Figure 4.9: Plot between Binder content vs. VMA

4.3.1.4 Binder content vs. VA

Table 4.16 Average VA and Bitumen content for DBM samples

Binder content (%)	VA (%)
4	5.91
5	4
6	3.1
7	3

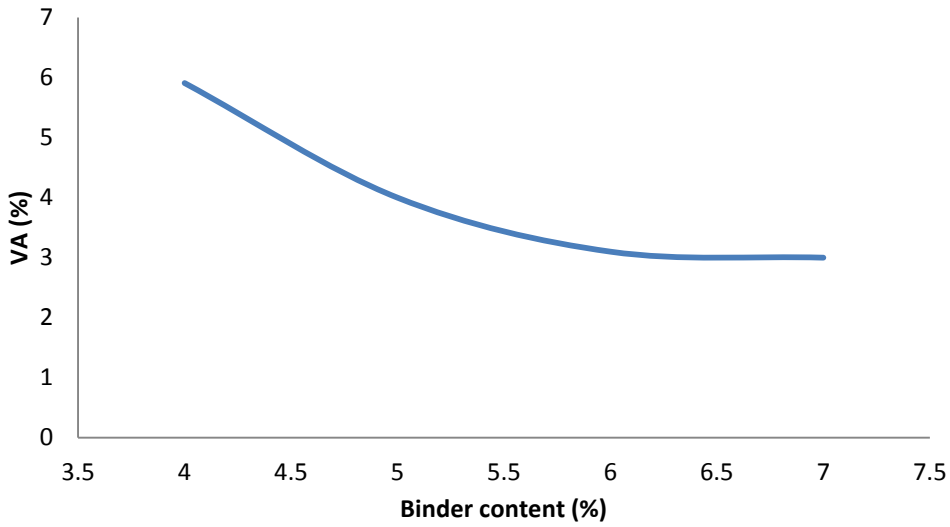

Fig 4.10: Plot between Binder content vs. VA

4.3.1.5 Binder content vs. VFB

Table 4.17 Average VFB and Bitumen content for DBM samples

Binder content (%)	VFB (%)
4	64.5
5	68
6	71
7	72

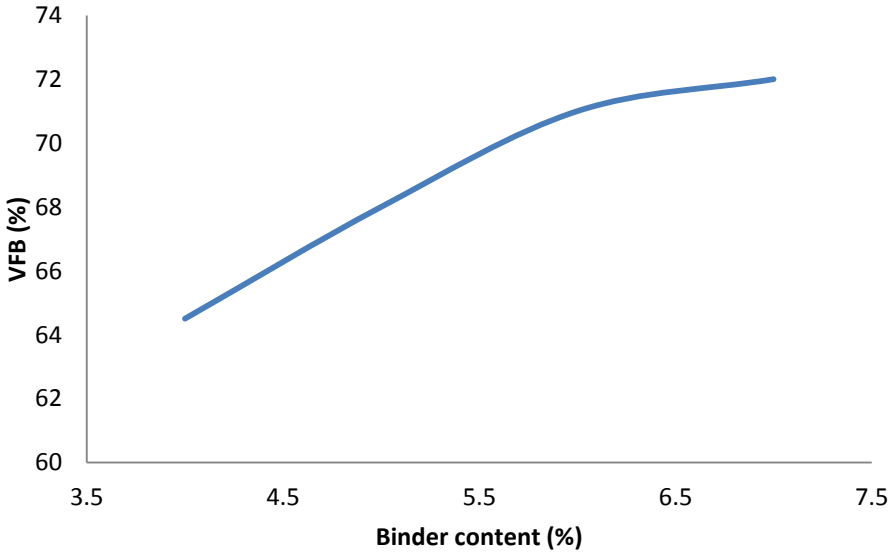

Figure 4.11: Plot between Binder content vs. VFB

4.3.1.6 Binder content vs. unit weight (G_{mb})

Table 4.18 Average unit weight and bitumen content for DBM samples

Binder content (%)	Unit weight (G_{mb})(kg/m^3)
4	2.432
5	2.482
6	2.548
7	2.516

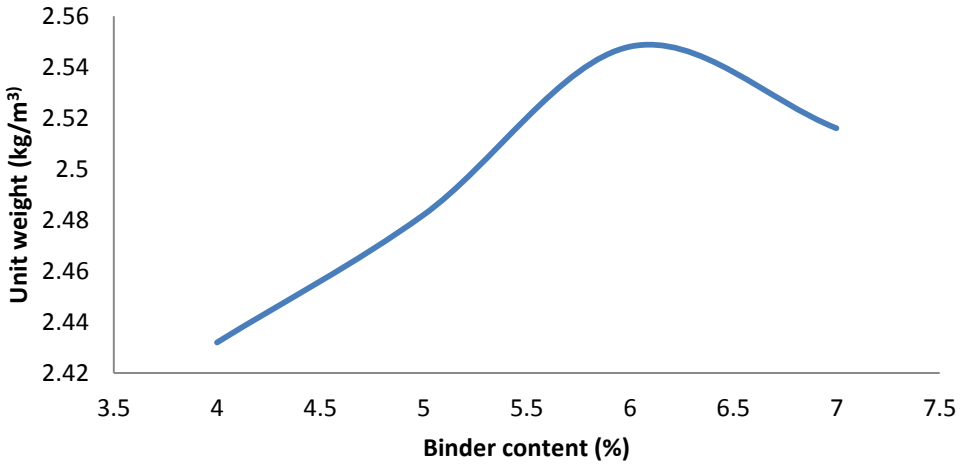

Figure 4.12: Plot between Binder content vs. unit weight

4.4 Determination of Mix Design Parameter

Optimum bitumen content= (A+B+C) / 3

Where A= bitumen content corresponding to maximum stability

B= bitumen content corresponding to maximum unit weight

C= bitumen content corresponding to 4 % air voids

Table 4.19 Mix properties at 4% air void

	SMA	DBM
Bitumen content (%)	5.93	5.33
Stability (kN)	9.6	12.9
Flow (mm)	2.5	2.35
VMA(%)	15.6	13.6
VFB(%)	71	69

4.5 Discussions

- From the relationships made above, it was found that optimum binder content for SMA and DBM samples were 5.93% and 5.33% respectively.
- Results and graphs obtained from Marshall test indicate that stability is gradually increasing with increase in bitumen and emulsion content and after certain percentage it was decreasing. Maximum stability value for SMA 11.65 kN and 13.28 kN for DBM mixes.
- Flow value of SMA and DBM samples gradually increases with increase in bitumen content. Initially flow value increases slowly, but after that with increase in bitumen content the of flow value increases rapidly.
- Theoretically VMA should remain constant for a given aggregate gradation with respect to binder content. But practically, it is observed that at low bitumen content, VMA slowly decreases with increase in bitumen content then increases after a pause.
- VA of Marshall test samples decreases with increase in bitumen content and VFB increases with increase in bitumen content.

Chapter V

CONCLUSIONS

5.1 General

Based on the results and discussion of Laboratory investigation on SMA and DBM mixes for WMA following conclusions are drawn.

5.2 Conclusions

In this observation, two types of mixes i.e. SMA and DBM specimens were prepared using VG 30 as binder tested on Marshall Test Apparatus. By Marshall Method of mix design, the optimum binder contents for both the mixes were found 5.93% and 5.33% for SMA and DBM respectively. When using Cationic Medium Setting type emulsion with binder, the properties of Mix was improved. Maximum stability value was observed for SMA 11.65 kN and 13.28 kN for DBM mixes. Flow value of SMA and DBM samples gradually increases with increase in bitumen content. VA of Marshall test samples decreases with increase in bitumen content and VFB increases with increase in bitumen content.

5.3 FUTURE SCOPE

- In future performance of bitumen emulsion as additive with other grades of bitumen can also be tested and seen whether it can be used successfully or not.
- Indirect tensile test of bituminous mixes can give us an idea about tensile strength of bituminous mixes.
- In future, samples also can be prepared at different temperatures.
- Wheel tracking test can give us idea about the rut resistance of the specimen.
- Use of other fillers or additives may result in better performance. So it may also be evaluated in future.

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